3.4 Target Signature Fluctuations Sensitivity Analysis

A complex moving target can be thought to consist of a finite number of predominant scattering centers, confined within the target extent, such that the backscattered target signal return continuously varies in phase and amplitude. The continuous variation in return target signal amplitude affects both the threshold for target detection and the efficiency of the radar receiver signal integrator. Additionally, the continuous variation in the phase of target signal returns results in a frequency spectral distribution of the signal, scintillation and glint, which may introduce target track errors.

The common approach to modeling these target signal fluctuations is the use of statistical target models. A great deal of work has been done by Swerling [A.1-26] and others to determine sets of statistical parameters that can categorize the target being modeled.

For ALARM 3.0, any one of eight statistically-categorized target types can be selected to best describe the target of interest. These statistical categorizations include: non-fluctuating target; Swerling cases 1, 2, 3, and 4; chi squared (χ^2); Weinstock; and log normal. See *Modifying an Existing One-on-One Radar Model for Unusual Target Statistics (An Example Using ALARM 84)* [A.1-26] for a complete description of the implementation. The eight different target types used in ALARM are identified and briefly described in table 3.4-1.

Table 3.4-1 Swerling Target Type Descriptions

Target Type	ALARM Target Type	Description
Non-fluctuating (Swerling Case 0)	0	Target does not fluctuate pulse-to-pulse or scan-to-scan.
Swerling Case 1	1	Slowly fluctuating cross section with multiple scatterers.
Swerling Case 2	2	Rapidly fluctuating cross section with multiple scatterers.
Swerling Case 3	3	Slowly fluctuating cross section with one main scatterer.
Swerling Case 4	4	Rapidly fluctuating cross section with one main scatterer.
Chi Squared (χ^2)	5	Can be used to emulate most other probability distribution functions (target types), given the correct parameters.
Weinstock	6	Special case of χ^2 , with number of degrees of freedom less than 1.0.
Log Normal	7	Slow fluctuation. Used to model scattering from highly directive reflectors when viewed from random aspects.

In applying any of the statistical target fluctuation categories there is some likelihood that the real target cannot be validly represented by any of the eight categories, or that a poorly matching category is selected. An incorrect categorization of target type and its associated fluctuation statistics will impact target detection. The difficulty of correctly identifying the target type is directly related to the difficulty in finding information linking specific aircraft types to probability density functions and the appropriate associated target model.

3.4.1 Objectives and Procedures

The objective of the sensitivity analysis is to assess the impact of the statistical target model on integration gain (function-level analysis) and target detection range (model-level analysis). At the function level, the measure of effectiveness (MOE) used to determine sensitivity is a 3 dB change in integration gain, when comparing the baseline case with the test cases. At the model level, the MOE is a 5% difference in normalized mean detection range, when comparing the baseline case with the test cases.

The FE-level analysis procedure is to develop an off-line driver to use the ALARM 3.0 subroutine THRESH to vary the target fluctuation type, producing discrete values for the detection threshold and integration gain. A square law integrator is used; the probability of detection (P_d) is set to 0.9 and the probability of false alarm (P_{fa}) is set to 10^{-6}. The data for the non-fluctuating target, considered the baseline case, are compared with those of the four Swerling cases, generally considered to characterize most target types.

The model-level procedure is to exercise ALARM in Contour Plot mode for each fluctuating target type. Only the non-fluctuating and Swerling cases are examined, with the non-fluctuating target designated as the baseline case. A square law integrator is used; the P_d is set to 0.9 and the P_{fa} is set to 10^{-6}. Initial detection ranges are compared to determine the impact of using the different target fluctuation types.

Table 3.4-2 identifies the specific parameters varied, and the output variables recorded, for these sensitivity analyses.

Table 3.4-2 ALARM Runs for Target Signature Fluctuations Sensitivity Analyses

Sensitivity Parameter	Analysis Level	Input Variable	Range of Variation	Output Variable	Test Case Description
Target Statistical Type	FE	ITTYPE	**0 (Non-Fluctuating)** 1 (Swerling Case 1) 2 (Swerling Case 2) 3 (Swerling Case 3) 4 (Swerling Case 4)	CONTOR, DBGAIN	Develop a driver program to access ALARM 3.0 subroutine THRESH to generate values for detection threshold and integration gain. Record detection threshold and integration gain for the five specified target types using a square law integrator; $P_d = 0.9$; $P_{fa} = 10^{-6}$.
	Model	IFLMOD	**0 (Non-Fluctuating)** 1 (Swerling Case 1) 2 (Swerling Case 2) 3 (Swerling Case 3) 4 (Swerling Case 4)	SIGTOI	Run ALARM in Contour Plot mode for each of the five target types, using a square law integrator; $P_d = 0.9$; $P_{fa} = 10^{-6}$. Determine initial detection range for each offset in each plot.

Note: Values in **bold** denote baseline case.

3.4.2 Results

Function Level: Figure 3.4-1 is a plot of integration gain vs. the number of pulses integrated as a function of statistical target type for a 0.9 P_d and 10^{-6} P_{fa}. As expected, the integration gain increases as the number of pulses increase for each statistical target type. Although the integration gain for Swerling 1, Swerling 3, and a non-fluctuating target are nearly the same, the detection thresholds (20.96 dB, 16.65 dB, and 12.33 dB, respectively) vary so that target detection may be impacted for these target types.

An apparent anomaly can be observed in figure 3.4-1. The integration gain for Swerling 2 and 4 target types can exceed the number of pulses integrated for conditions where the number of pulses integrated is less than 10. For a non-coherent integrator, the integration gain is expected to fall between $\sqrt{N}$ and N, where N is the number of pulses integrated. The apparent anomaly can be explained by the definition of integration gain for fluctuating targets, which is the ratio of the S/N detection threshold for N pulses to the S/N detection threshold for a single pulse, rather than the ratio of integrator gain for N pulses relative to the gain for a single pulse.

Table 3.4-3 Detection Threshold (dB) as a Function of Target Fluctuation Model ($P_d = 0.9$, $P_{fa} = 10^{-6}$)

Non-Fluctuating	Swerling Case 1	Swerling Case 2	Swerling Case 3	Swerling Case 4
12.33	20.96	20.96	16.65	16.65

The integration gain for target types Swerling 2 and 4 are significantly different, exceeding the 3.0 dB MOE criteria. This is clearly shown in figure 3.4-2, a plot of the difference in integration gain vs. number of pulses integrated as a function of statistical target type.

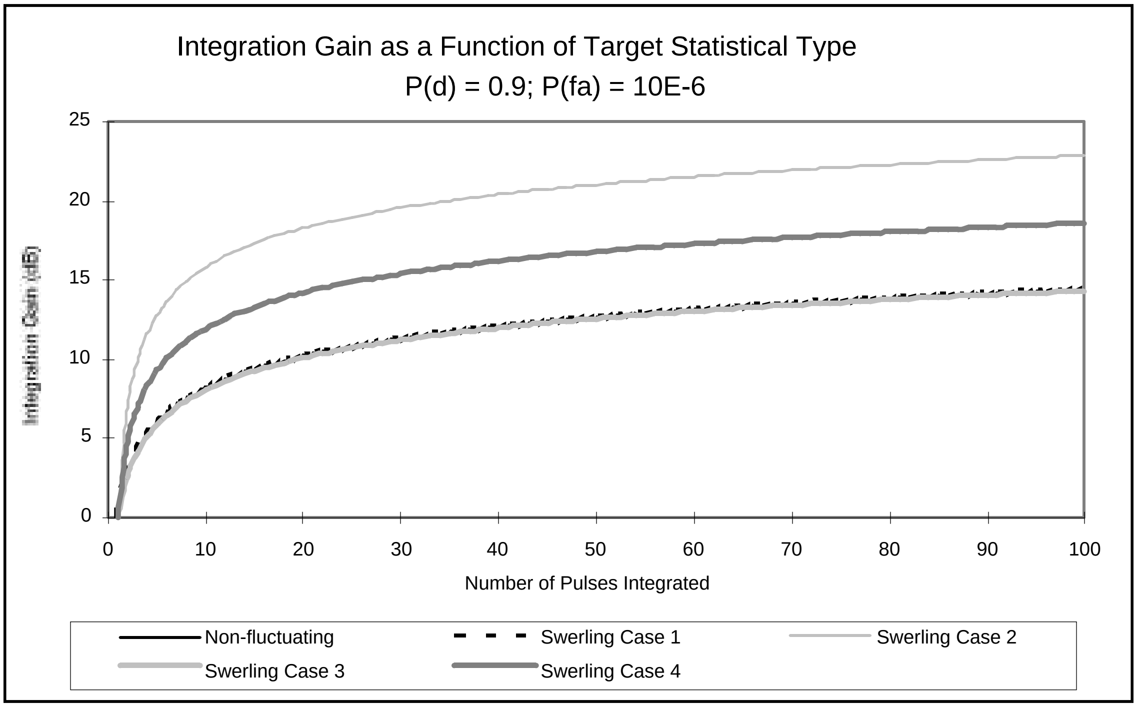

Figure 3.4-1 Integration Gain for P_d=0.9, P_{fa}=10^{-6}, 1 through 100 Pulses

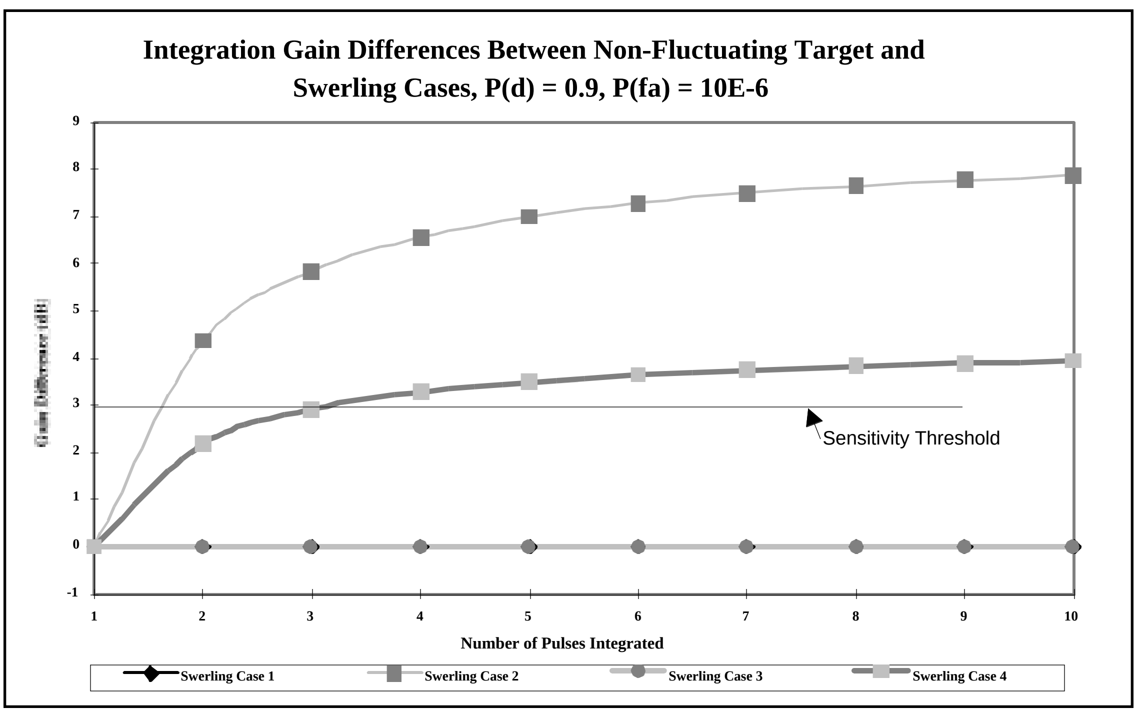

Figure 3.4-2 Integration Gain Difference for P_d=0.9, P_{fa}=10^{-6}, 1 through 10 Pulses

Model Level: Figure 3.4-3 shows plots of target detection range vs. target offset as a function of fluctuating target type. Note that the non-fluctuating target and Swerling Cases 2 and 4 show quite similar initial detection ranges. This similarity is not intuitively apparent since the greatest difference in integration gain occurs for these target types. However, the threshold for target detection also varies as a function of target type, offsetting the differences in integration gain.

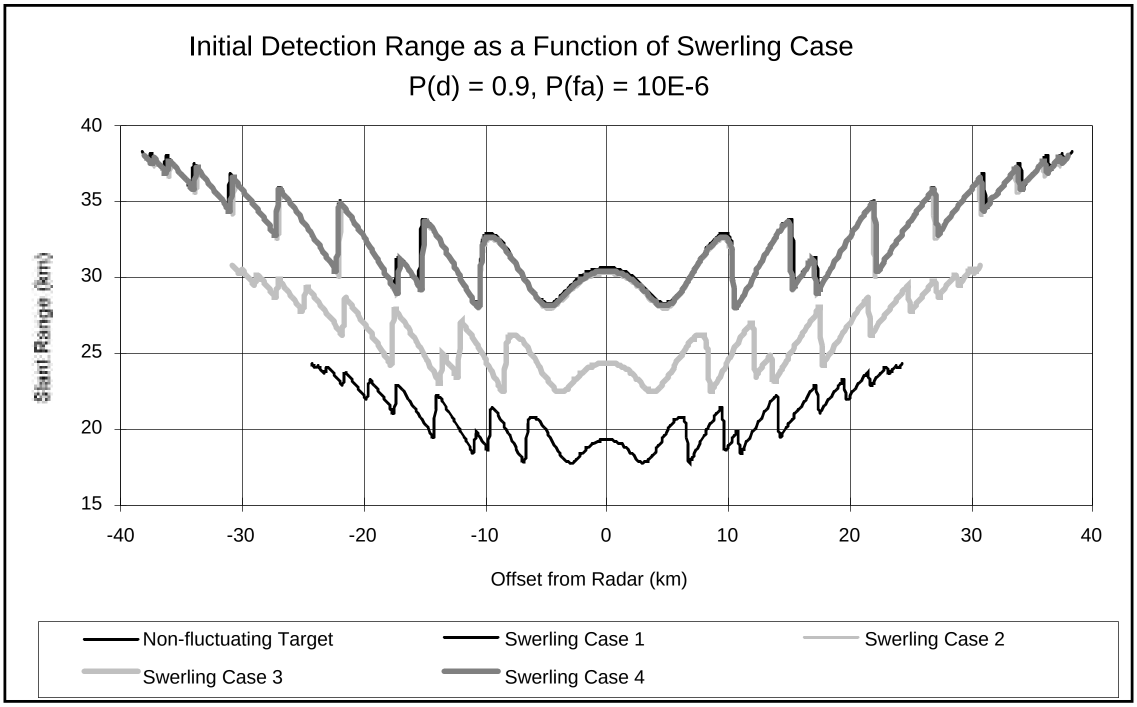

Figure 3.4-3 Initial Detection Range as a Function of Swerling Case, $P_d = 0.9$, $P_{fa} = 10^{-6}$

The normalized statistics (table 3.4-4) confirm that the initial detection ranges for targets characterized as Swerling Cases 2 and 4 are nearly the same as the non-fluctuating target, the baseline case. Both Swerling Cases 1 and 3 differ significantly from the baseline case.

Table 3.4-4 Initial Detection Range Statistics for Swerling Cases, $P_d = 0.9$, $P_{fa} = 10^{-6}$

Target Type	Mean (m)	σ (m)	Normalized Mean Difference	% Change
Non-fluctuating (baseline)	32,819	2,844	-	-
Swerling Case 1	20,762	1,866	-0.225	-36.74
Swerling Case 2	32,391	2,799	-0.007	-1.30
Swerling Case 3	26,157	2,330	-0.113	-20.30
Swerling Case 4	32,610	2,840	-0.003	-0.64

3.4.3 Conclusions

Target signal fluctuation statistics are not defined for most target types. Since target fluctuation characteristics can significantly impact the prediction of target detection, collection of validation data for this functional element is of the highest priority. Assuming that target fluctuations are unique for each target and flight conditions, validation data collection should be conducted for a broad array of target types, target flight conditions, and radar types. It is essential to measure pulse-to-pulse signal amplitude, system integration gain, and the threshold for detection for each target type and flight condition in order to validate this functional element.

The user should be aware of the sensitivity of the model to the choice of statistical target and should be further aware that the specific target of interest may not fall within the statistical target types currently available in ALARM.